The formation of galaxy disks*: what have we learnt from cosmological hydrodynamical simulations? *Kinematics

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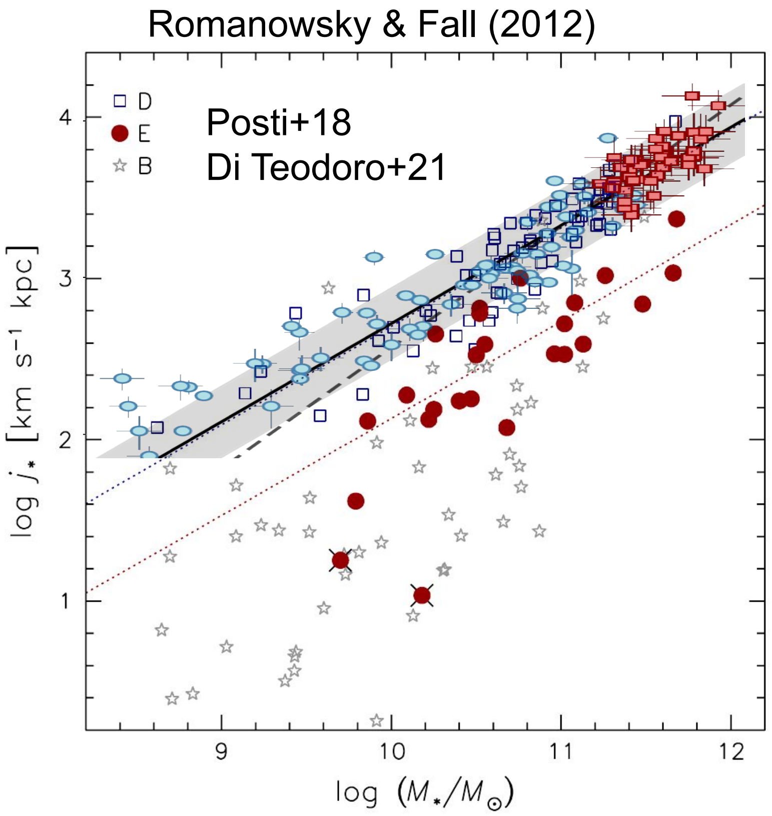
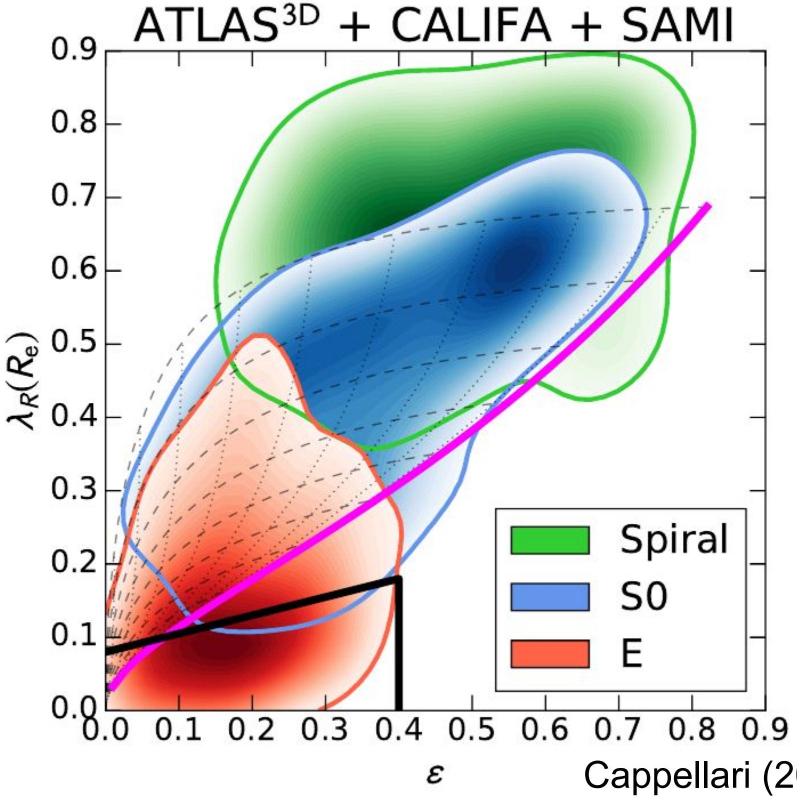
Some fundamental properties of galaxy disks





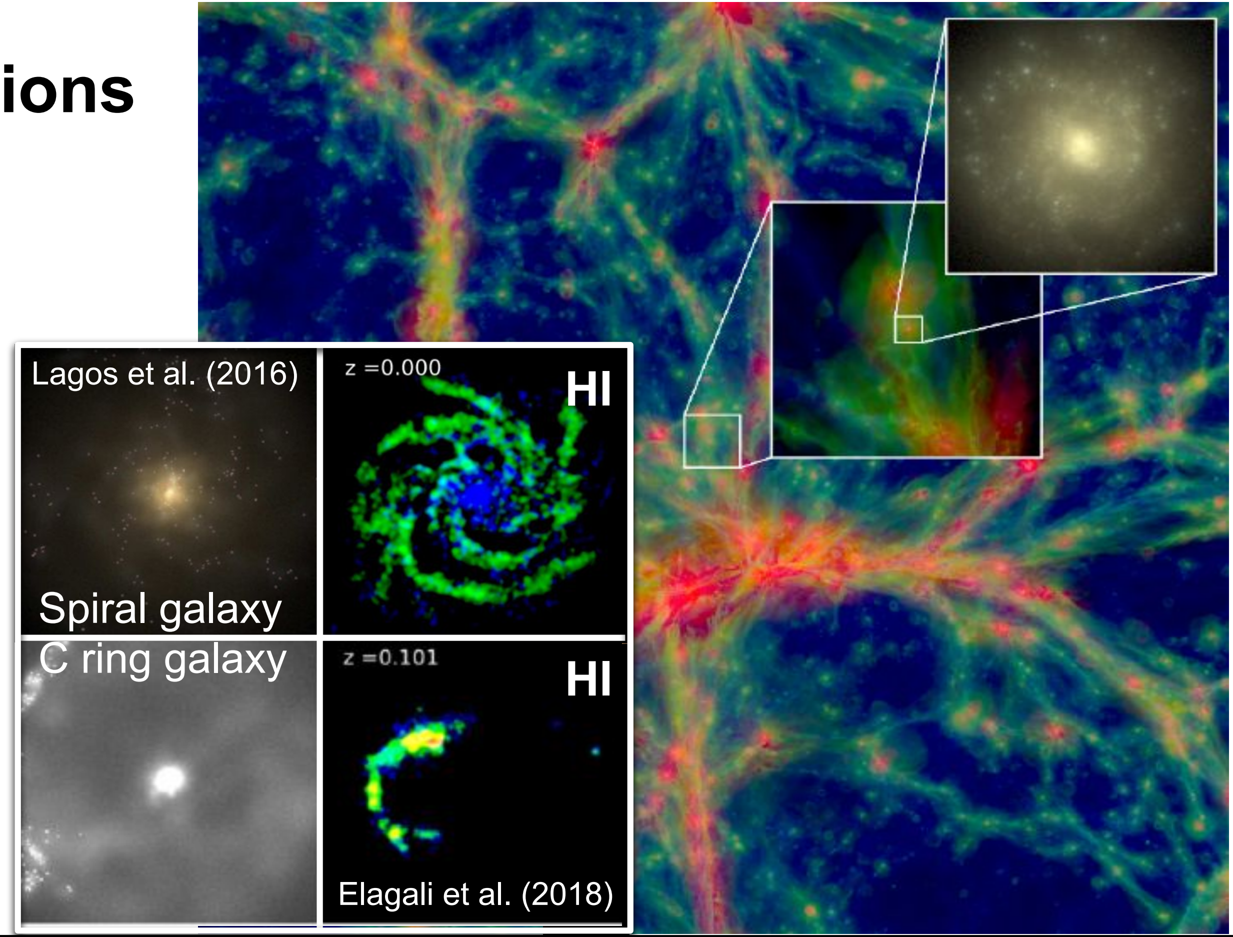
Cappellari (2016)

The EAGLE simulations

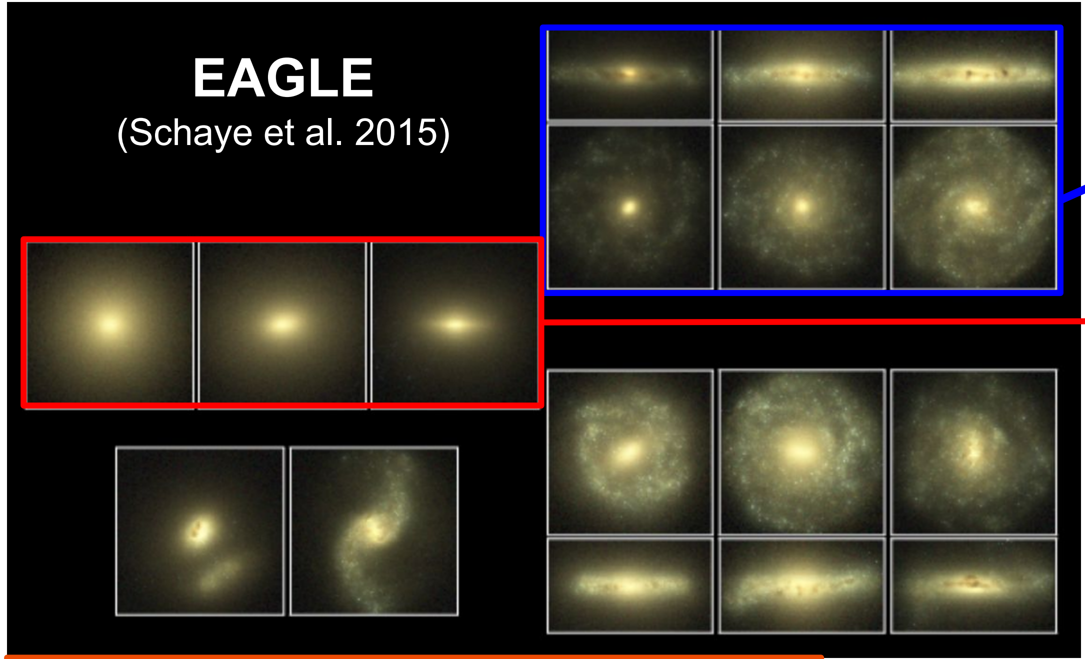
- 100Mpc
- $m_b = 1.81 \times 10^6\ M_\odot$
- $m_{dm} = 9.70 \times 10^6\ M_\odot$
- $\varepsilon_{prop} = 700pc$
- 6.8billion particles

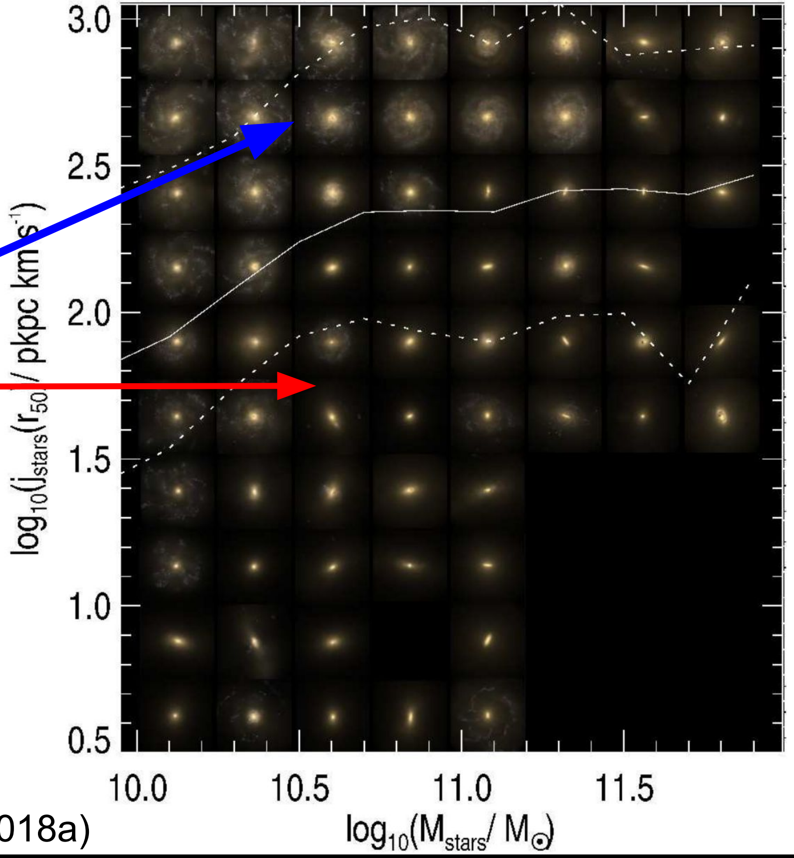
- Metal-dependent cooling
- Reionisation
- Star formation
- Stellar recycling
- Black hole growth/mergers
- SNe feedback
- AGN feedback

Schaye et al. (2015), Crain et al. (2015)
~300 papers written with EAGLE



The connection between AM and morphology



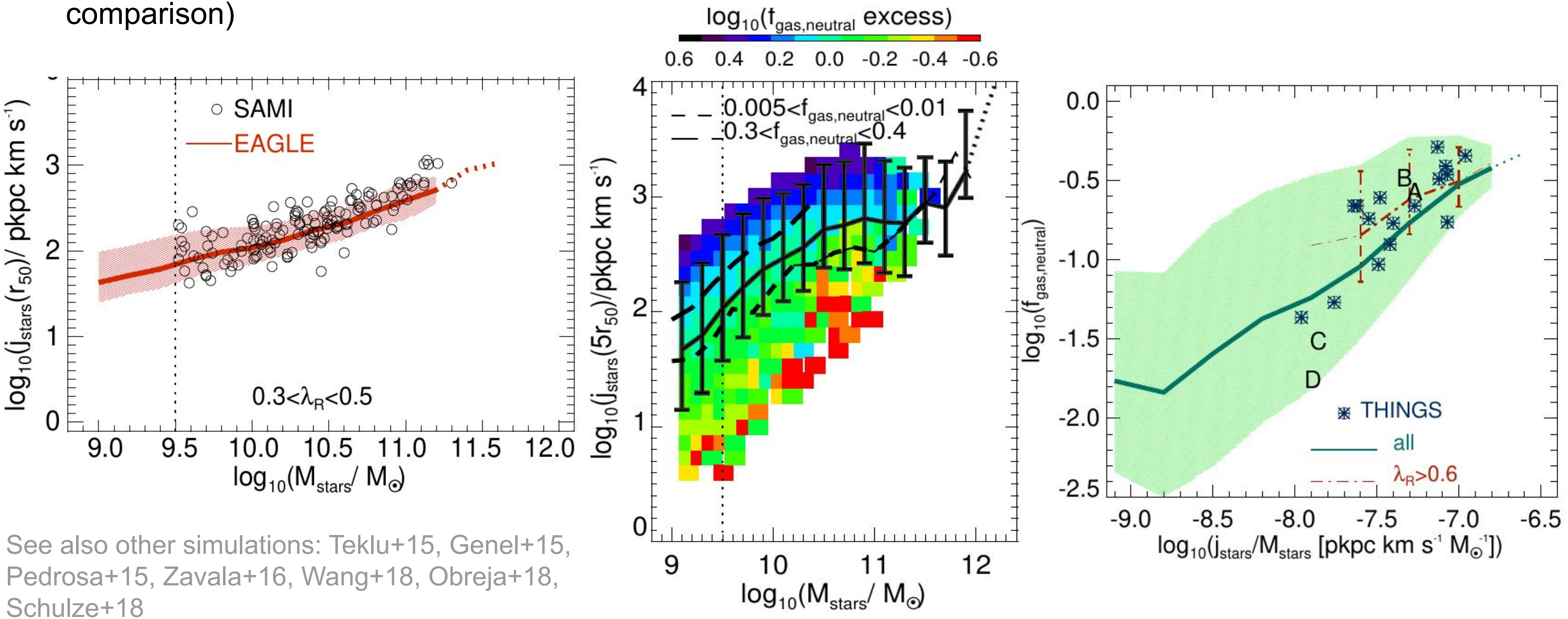


Lagos et al. (2018a)

Asking what gives rise to the Hubble sequence is *similar* to asking how galaxies gain their AM

Successes in reproducing disk properties

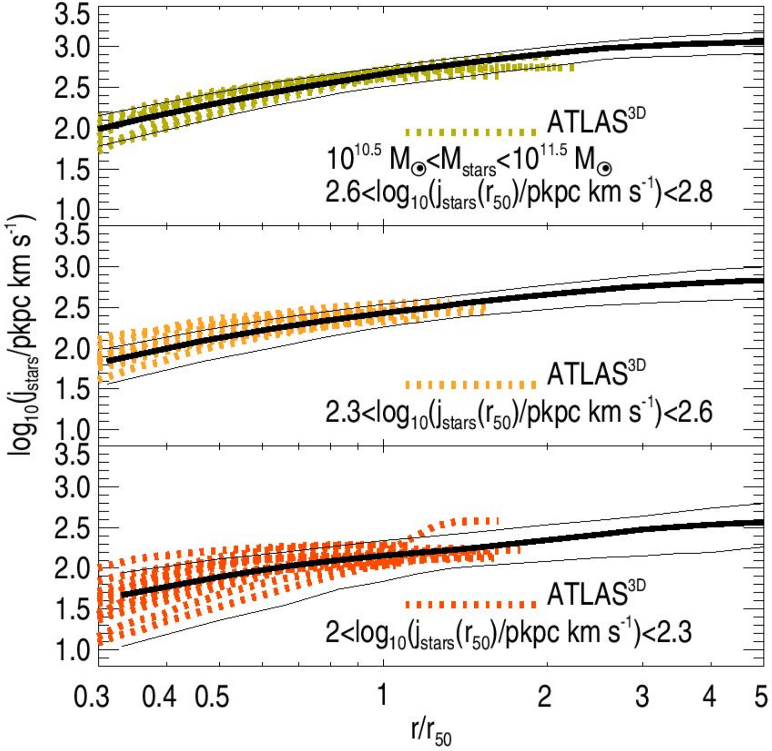
Lagos et al. (2017): Testing EAGLE against AM measurements at z=0 (see Swinbank et al. 2017 for a high-z comparison)



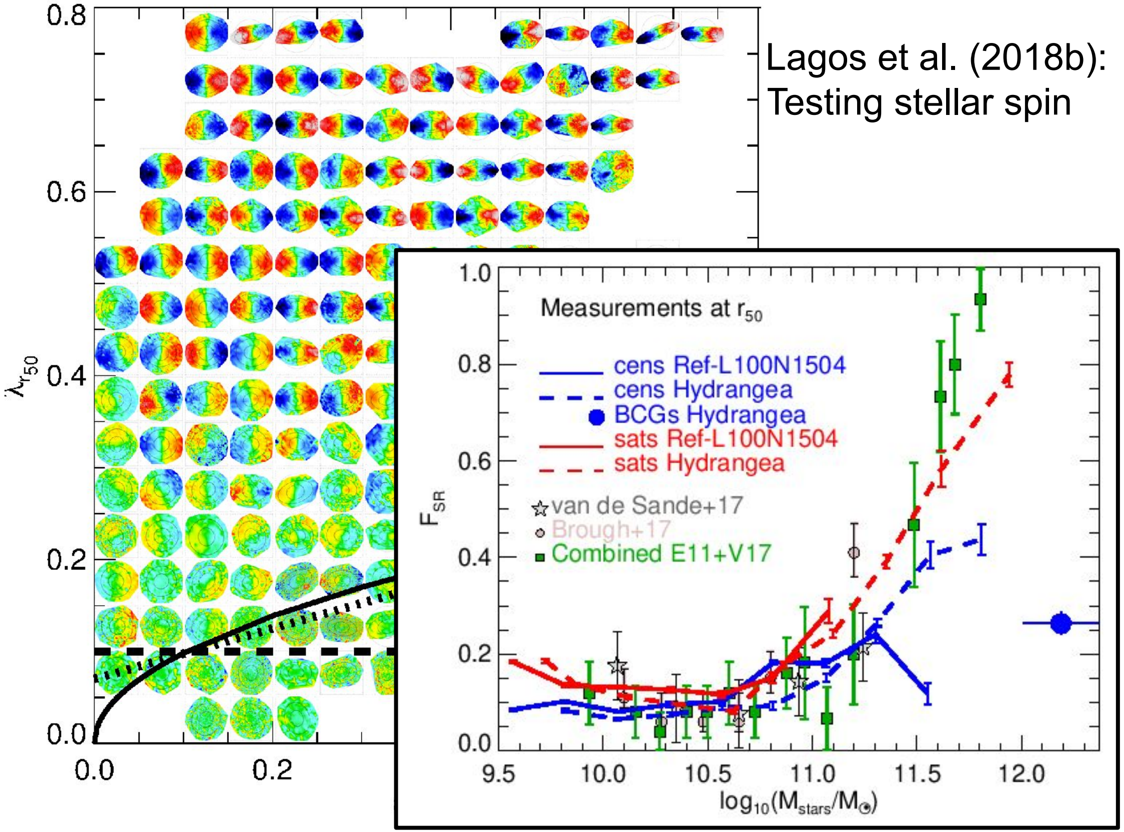
See also other simulations: Teklu+15, Genel+15, Pedrosa+15, Zavala+16, Wang+18, Obreja+18, Schulze+18

Successes in reproducing disk properties

Lagos et al. (2018a): jstar AM profiles



Lagos et al. (2018b): Testing stellar spin



See also Pulsoni et al. (2019), Walo-Martin et al. (2020)

How do disks acquire their angular momentum?

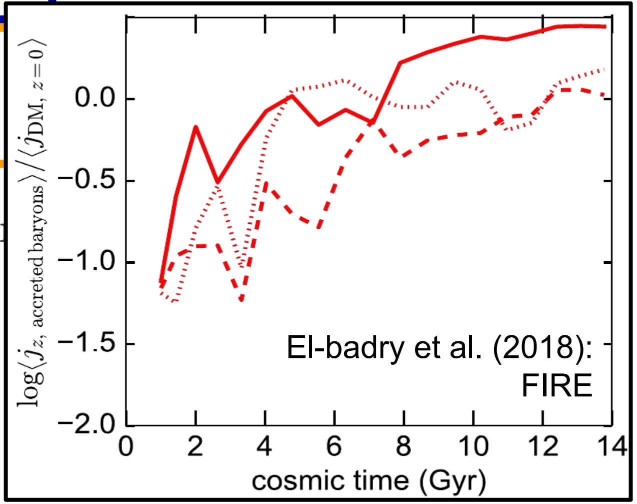
Lagos et al. (2017): EAGLE

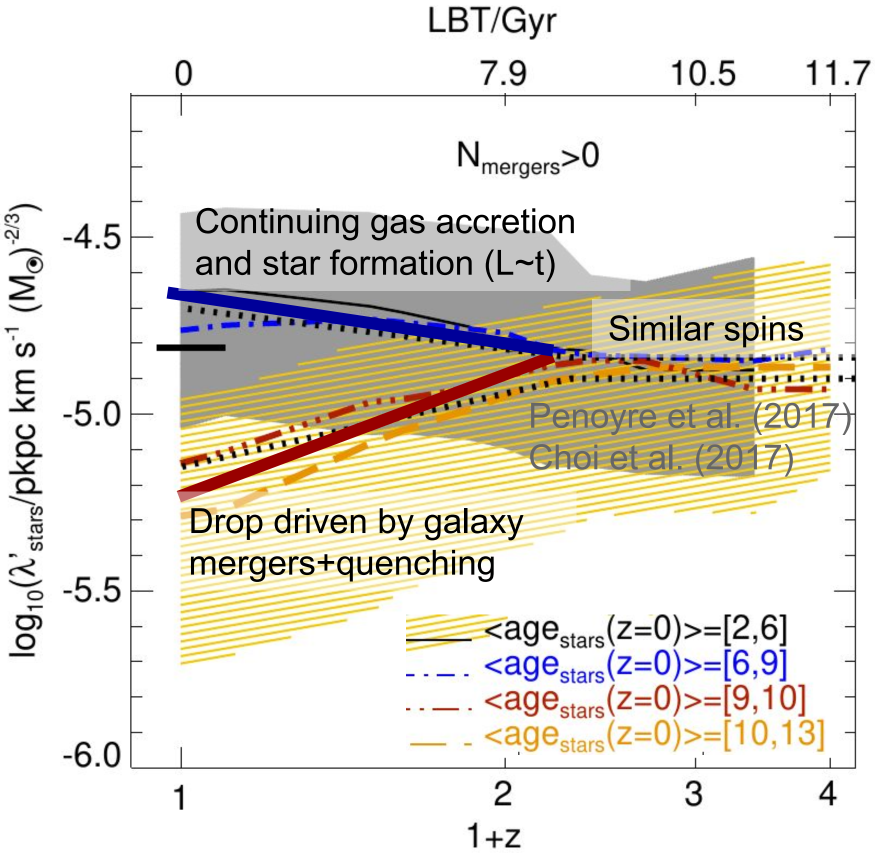
z=0 population

Young, high j

Old, low j

$\lambda'_{\rm stars} \equiv j_{\rm sta}$





How do disks acquire their angular momentum?

Lagos et al. (2017): EAGLE

z=0 population

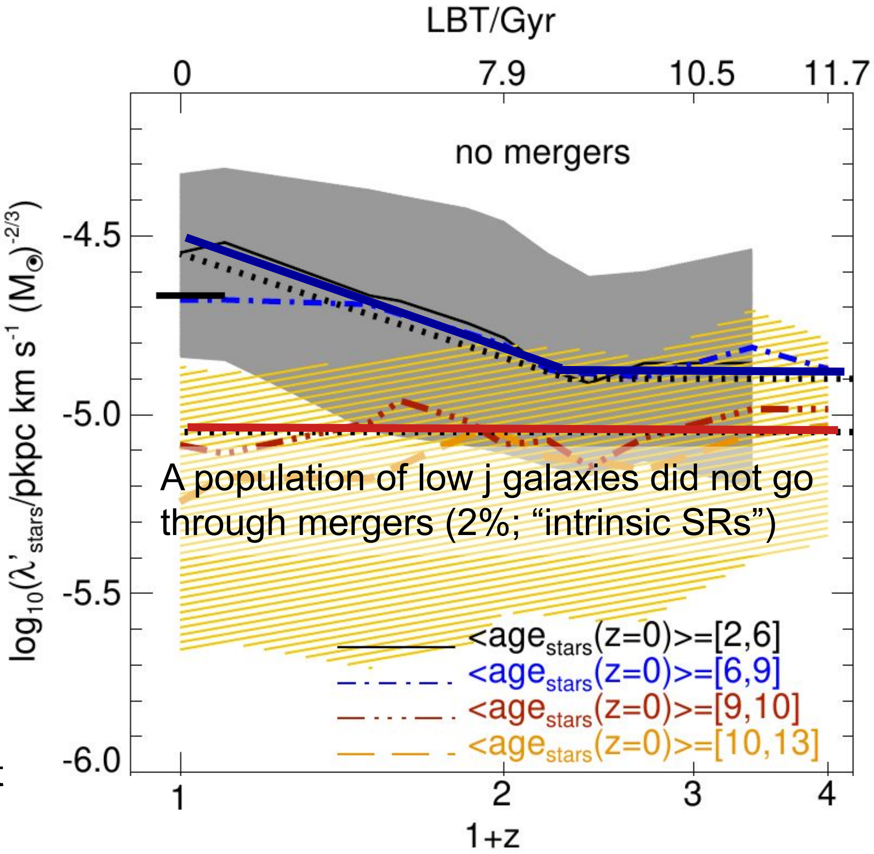
Young, high j
Old, low j

$$\lambda'_{\rm stars} \equiv j_{\rm stars}(r_{50})/M_{\rm stars}^{2/3}$$

MAGPI

Foster, Mendel, Lagos, Wisnioski et al. (2021)

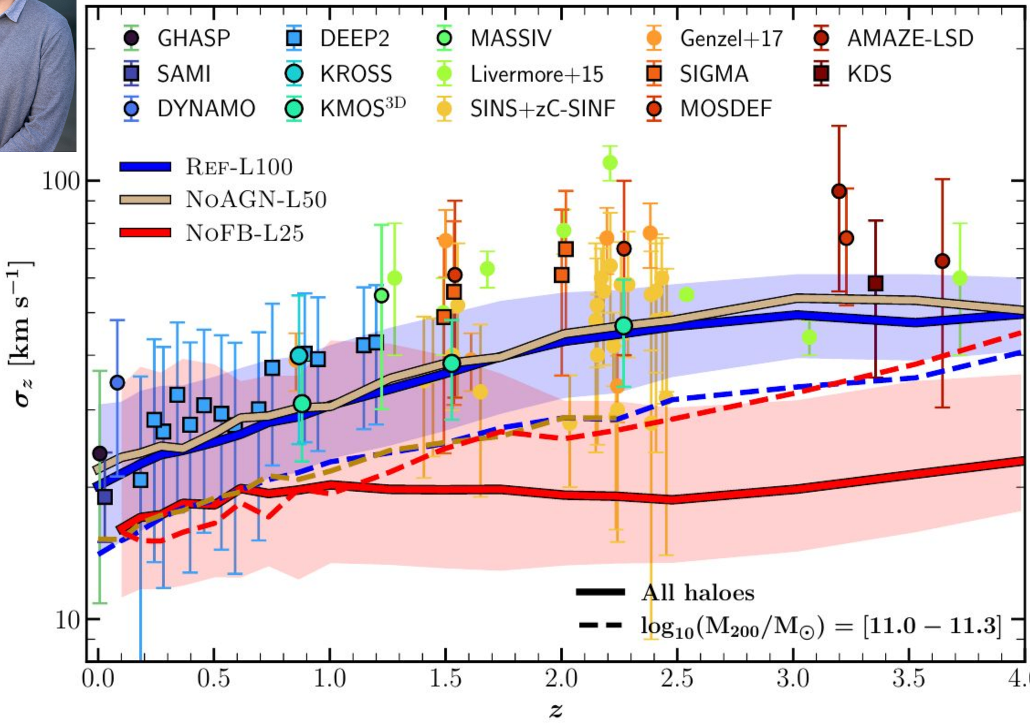
MUSE LP (350+ hr) to observe galaxies at 0.3<z<0.5 in different $M_{\rm halo}$

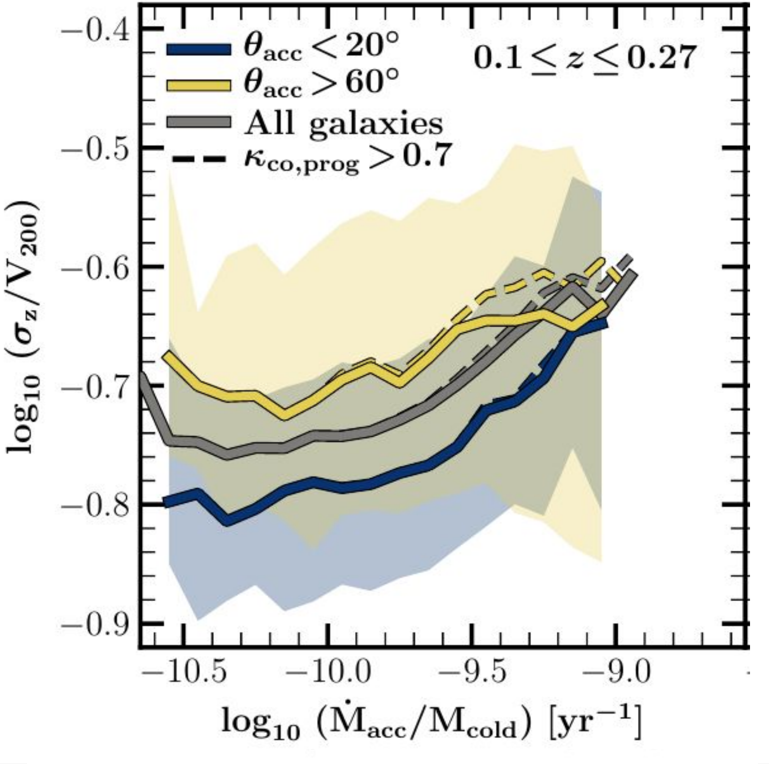


A population of low j galaxies did not go through mergers (2%; "intrinsic SRs")

Why is later accretion efficient at spinning up?

Jimenez, Lagos, Ludlow & Wisnioski (in prep)

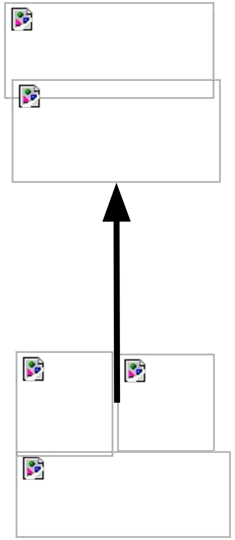




See also Pillepich et al. (2019); Forbes et al. (2022); Hafen et al. (2022)

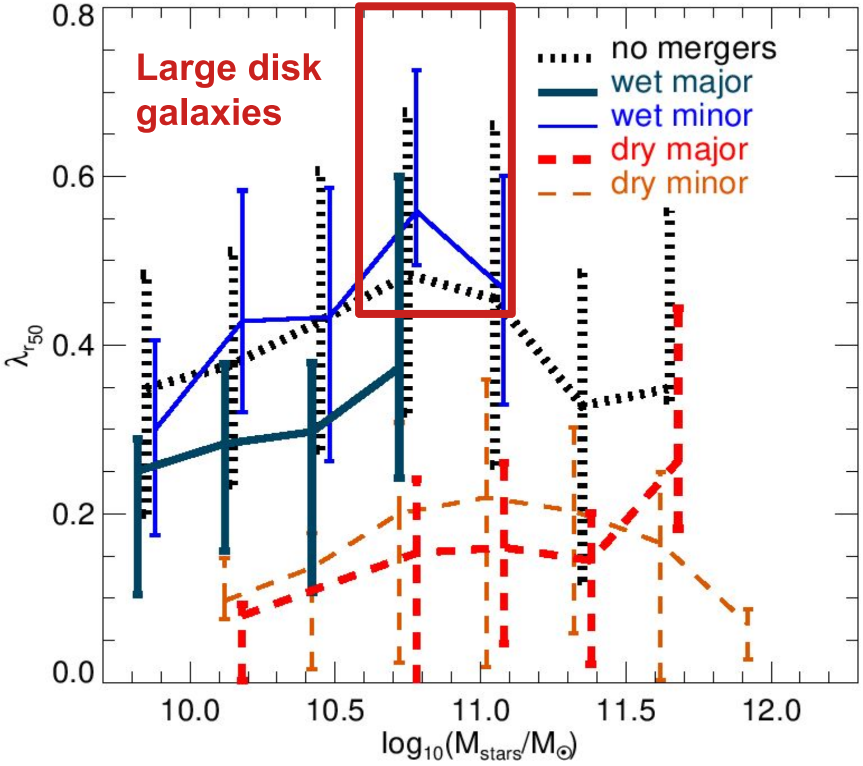
Galaxy mergers and their role in disk formation

Rotation dominated



Dispersion dominated

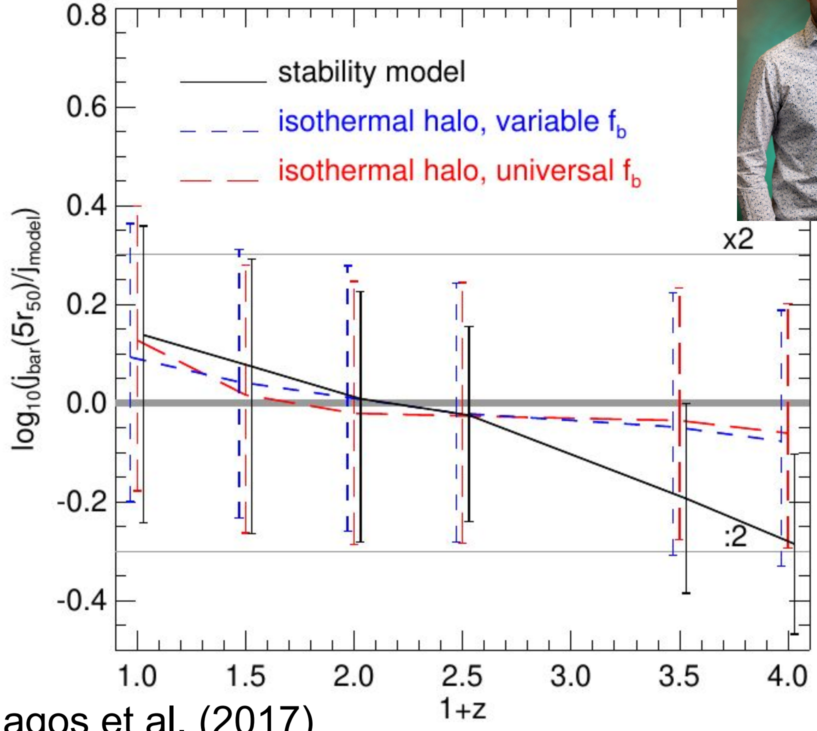
Lagos et al. (2018b)



CAVEAT: EAGLE disks are too thick (van de Sande et al. 2019)

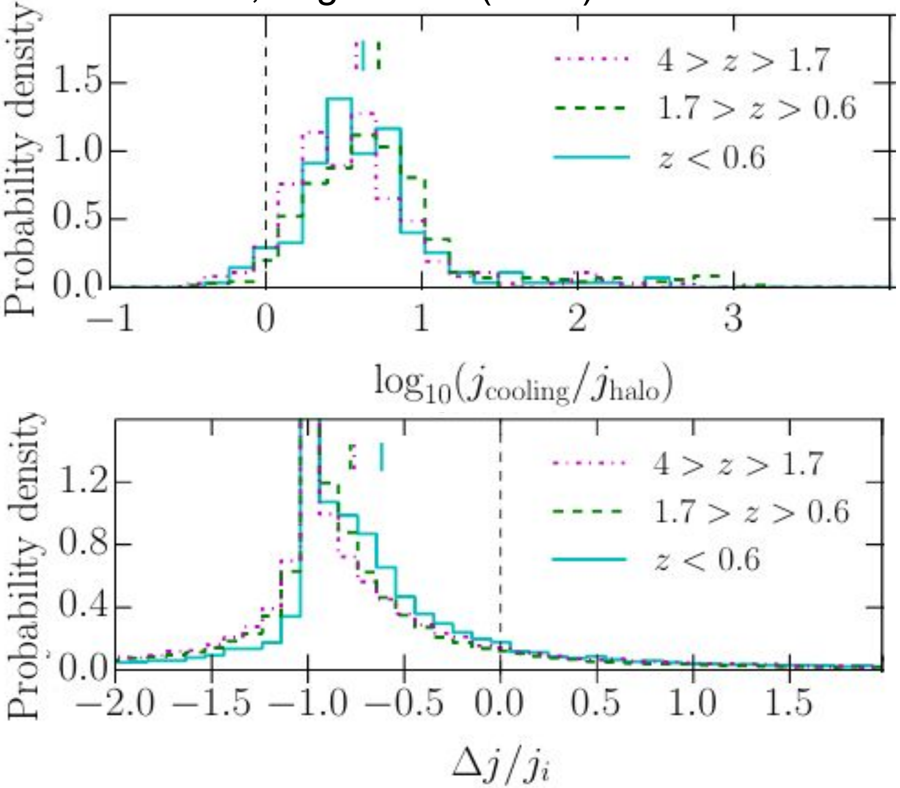
Issues with the classical AM picture of discs

Mo, Mao & White (1998) and $j_{\rm bar} =$



Lagos et al. (2017)

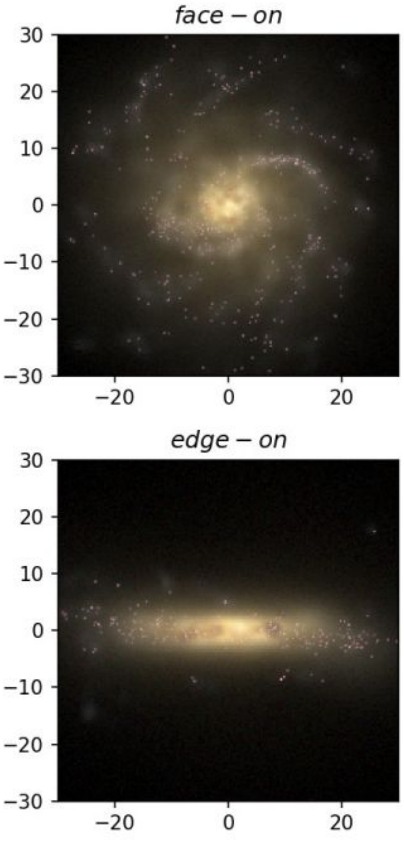
Stevens, Lagos et al (2017): MW-like halos

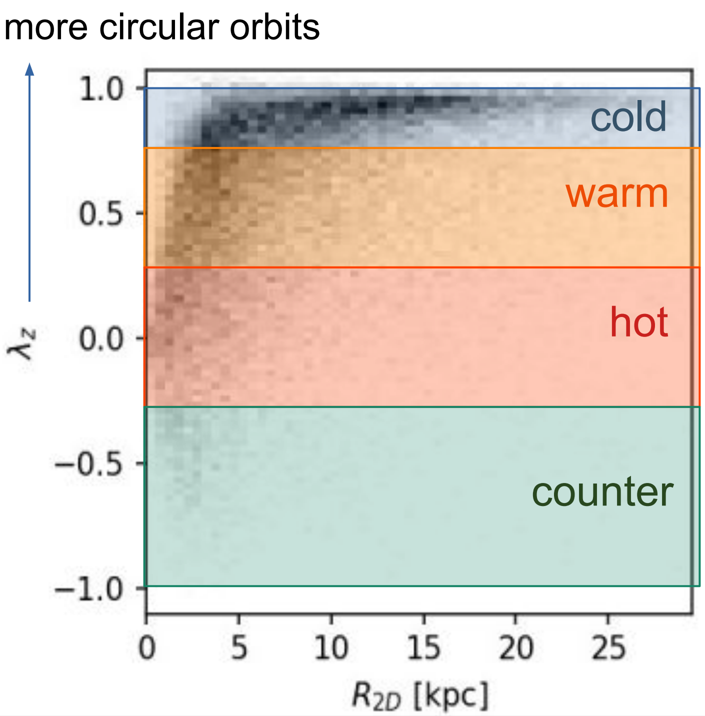


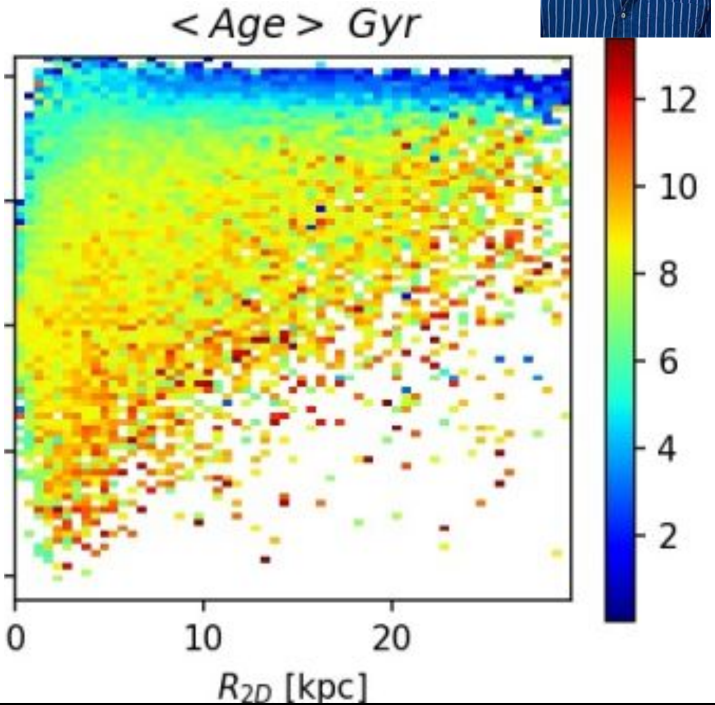
See also Danovich et al. (2015), Stewart et al. (2017), Garrison-Kimmel et al. (2017)...

Beyond $j_\star$, λ_r: classifying stellar orbits

Daniel Walo-Martin, Lagos in prep







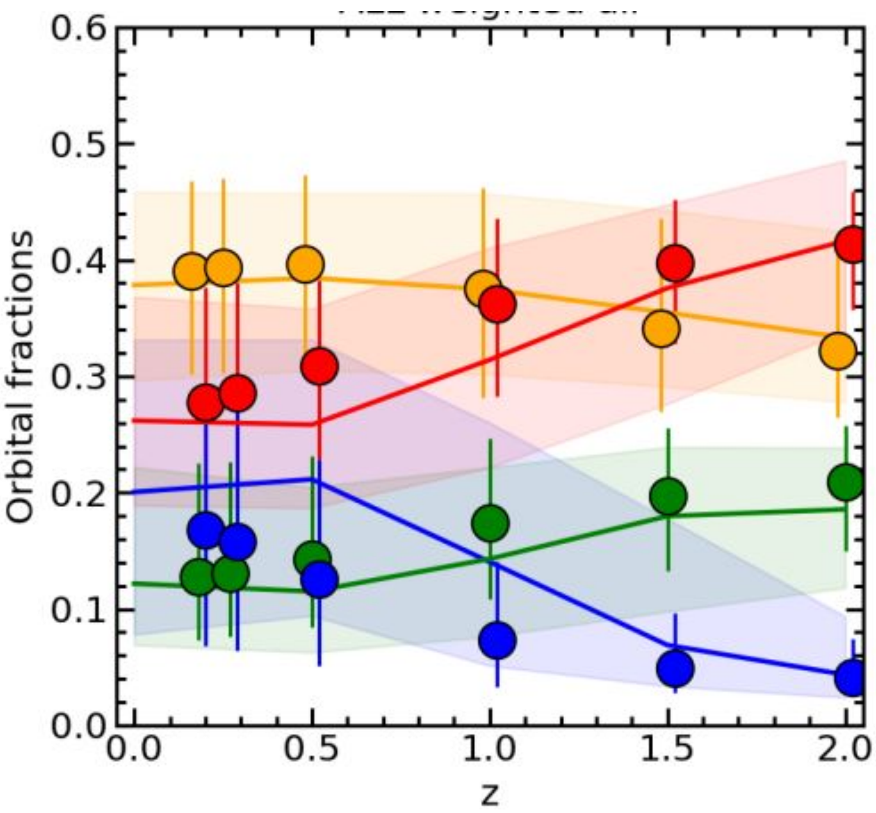
Beyond $j_\star$, λ_r: classifying stellar orbits

cold

warm

hot

counter

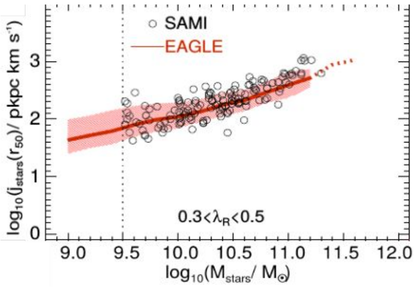


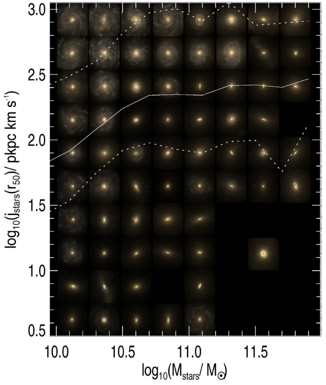
Daniel Walo-Martin, Lagos in prep

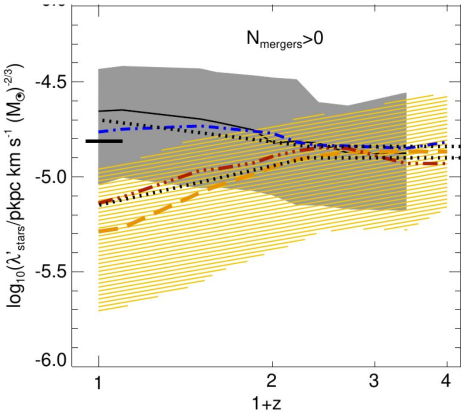
Motions within the disk change the orbital fractions by ~15%

Conclusions

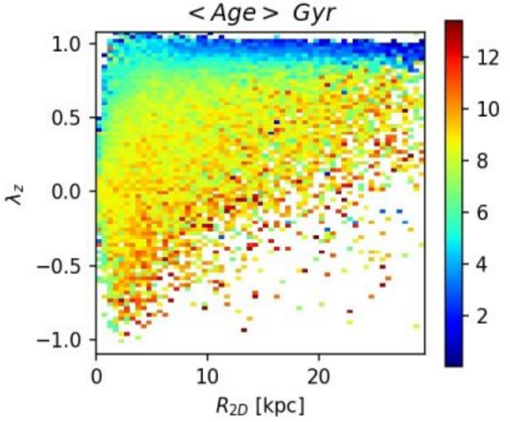
(1) Current simulations are able to *reproduce reasonably well the morphological diversity* of galaxies and j-M relation (**caveat of flat disks, ε>0.8**)







(2) For galaxies to have *high j, later gas accretion and star formation is preferred*, alignment facilitates spin up significantly. For low j, *two clear channels are found:* galaxy mergers and early quenching.

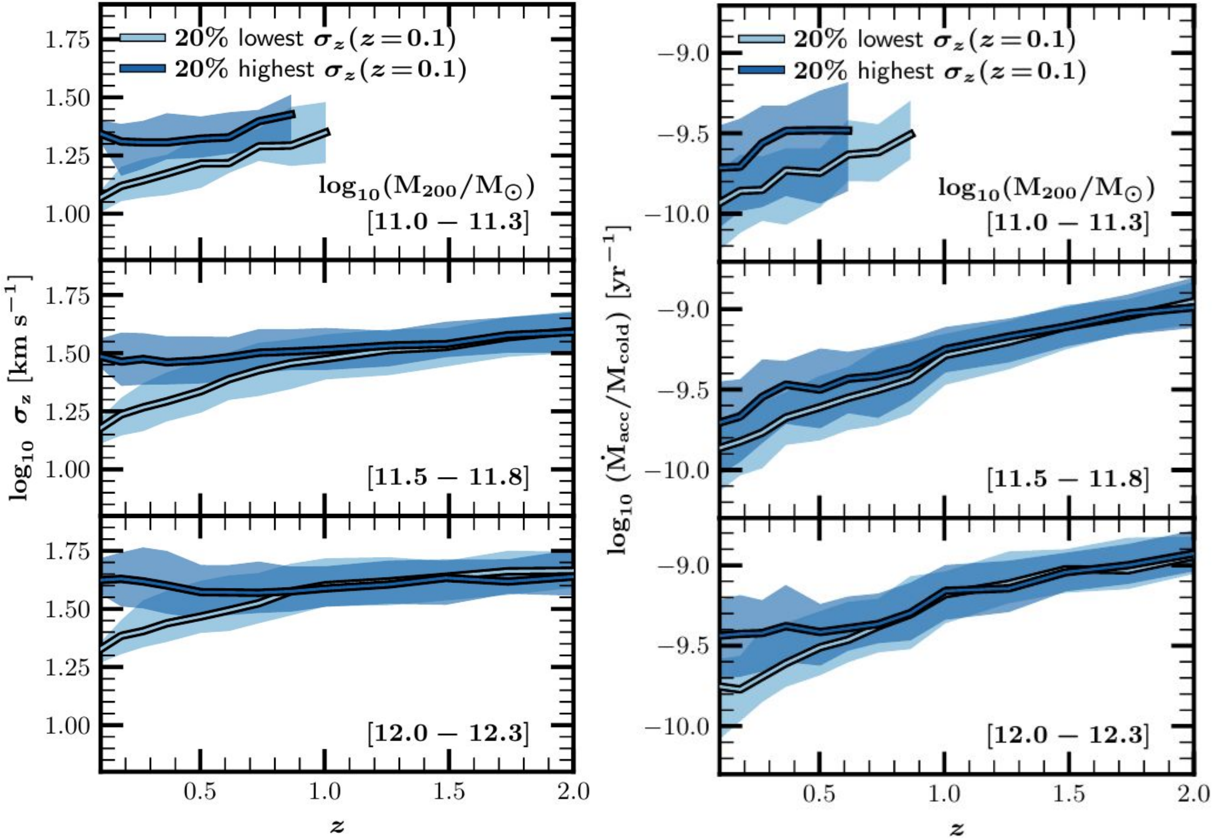


(3) Moving towards analysing *simultaneously stellar pops and kinematics* and applying the same models to simulated IFS cubes

(4) Classical understanding of disk formation holds on average, but details are *much more complex*

Lagos et al. (2017, 2018a, b), Stevens et al. (2017), Foster et al. (2021), Jimenez et al. (in prep), Walo-Martin et al. (in prep)

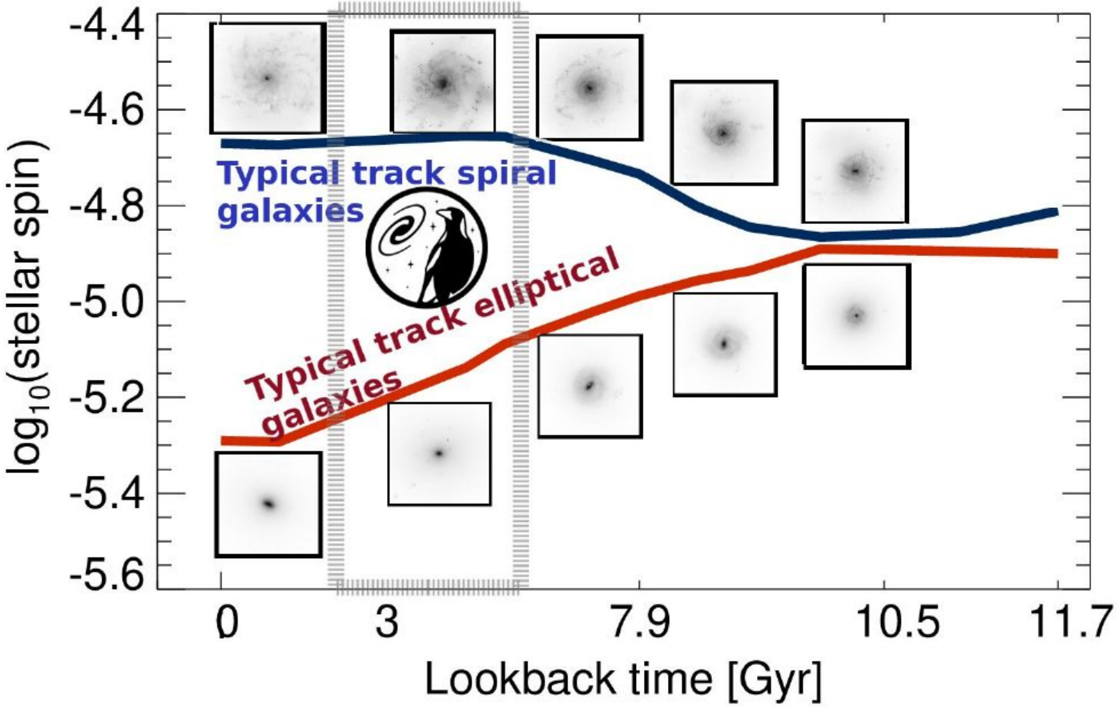
ISM turbulence as a galaxy characteristic



The MUSE Large Program MAGPI

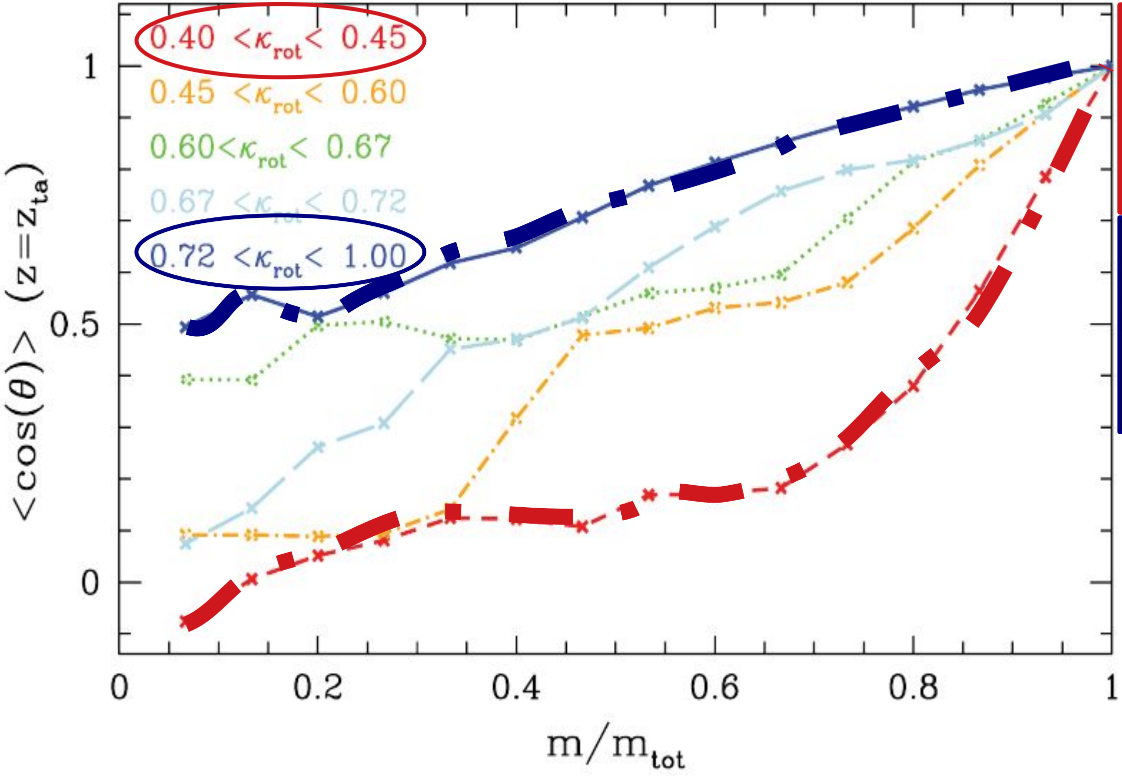
One of the motivations of MAGPI was the model predictions of significant morph transformation at z<0.5 (Foster et al. 2021).

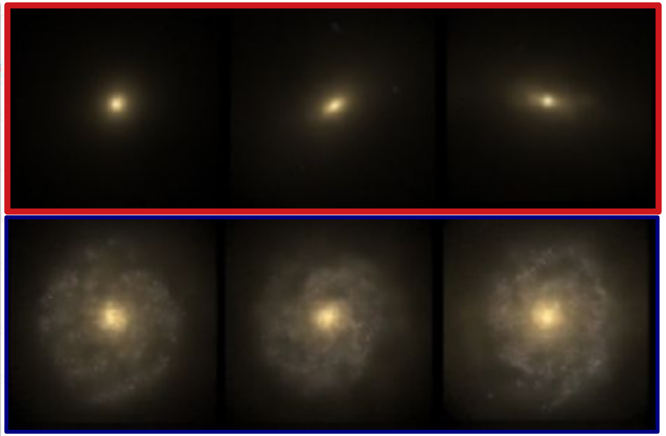
EAGLE simulations
DP21 (Lagos+):
modified from
Lagos et al. (2017)
Lagos (2020; review)



Why is later accretion efficient at spinning up?

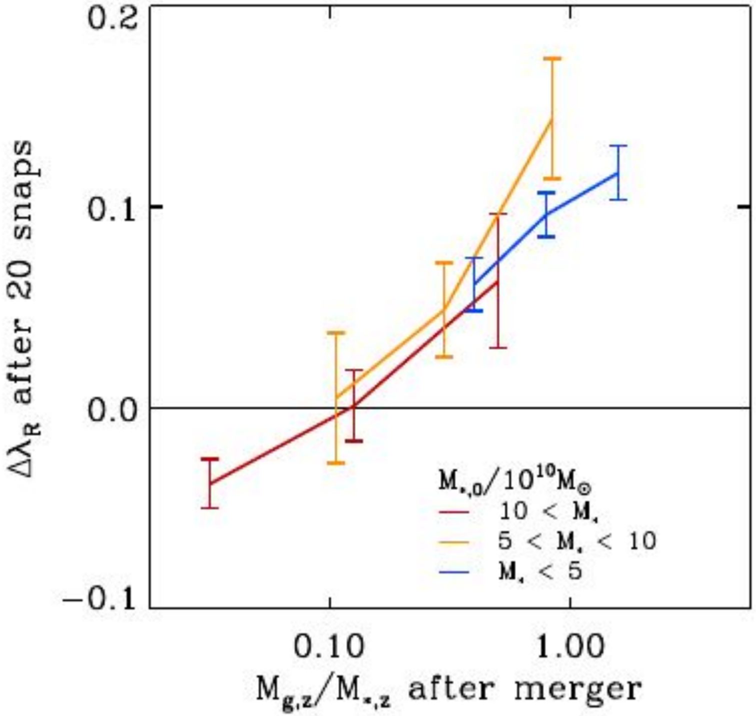
Sales et al. (2012): higher alignment linked to higher spins



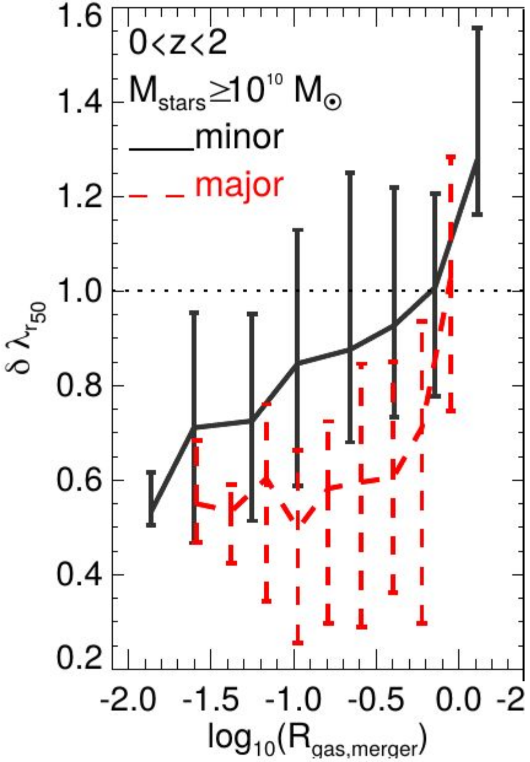


Mergers and the spin up/down of galaxies

Penoyre et al. (2017)



Lagos et al. (2018b)



The formation of galaxy discs

- Talk about galaxy disk properties that I'll be looking at
- Introduce EAGLE and the morphological diversity of galaxies
- Talk about AM vs morphology relation (Lagos18a)
- Gas fraction vs AM (Lagos17)
- Angular momentum acquisition (Lagos17)
- Complexity of angular momentum problem (cooling etc; Stevens+17)
- lambdaR vs. stellar mass and ellipticity vs merger history (Lagos18b)
- Issues with thin disks in EAGLE (van de Sande et al. 2019)
- Turbulence in galaxy disks and effect of gas accretion (Esteban's stuff)
- Stellar dynamics internal to galaxies (Daniel Walo-Martin's stuff)